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Some Studies on Forming Optimization with Genetic Algorithm

Ganesh M. KAKANDIKAR[a] and Vilas M. NANDEDKAR[b]

[a] Assistant Professor in Mechanical Engineering Department, Zeal Education Society's Dnyanganga College of Engineering, Pune, Maharashtra, 413133 - India.
Email: kakandikar@yahoo.co.in

[b] Professor in Production Engineering Department, Shri Guru Gobind Singhji Institute of Engineering and Technology, Nanded, Maharashtra, 431606 - India.
Email: vilas.nandedkar@gmail.com

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Abstract. Forming is a compression-tension process involving wide spectrum of operations and flow conditions. The result of the process depends on the large number of parameters and their interdependence. The selection of various parameters is still based on trial and error methods. In this paper the authors present a new approach to optimize the geometry parameters of circular components, process parameters such as blank holder pressure and coefficient of friction etc. The optimization problem has been formulated with the objective of optimizing the maximum forming load required in Forming. Genetic algorithm is used as a tool for the optimization: to optimize the drawing load and to optimize the process parameters. A finite element analysis simulation software Fast Form Advanced is used for the validations of the results after optimization with prior results.

Keywords: Sheet metal; Forming; Genetic algorithm; Optimization.
AMS Classification: 90-08, 74S05

1. Forming Process Overview

In forming process the blank is generally pulled over the draw punch into the die; the blank holder prevents the wrinkling taking place in the flange. There is great interest in the process because there is a continuous demand on the industry to produce light weight and high strength components. The large number of parameters involved in forming and their interdependence makes the process more complex. These subjects have been studied in [1-6] with different perspectives. The parameters are material properties, machine parameters such as tool and die geometry, work piece geometry and working conditions. The overall quality and performance of the object formed depends on the distribution of strains in the sheet material. Material properties, geometry parameters, machine parameters and process parameters affect the accurate response of the sheet material to mechanical forming of the component. The stretching primarily depends on the limit strains.

The limit strains are described by the concept of forming limit diagram. The forming limit represents the onset-localized necking over all possible combinations of strains in the plane of the sheet. Recently, sensitivity analysis combined with incremental FEM has been widely studied by many researchers so as to identify optimal conditions automatically. Nowadays, simulation-based-design approaches have been used for forming processes, which carries many similar simulations with different process parameters and different tool geometries. It is not sure whether the optimal process parameters and tool geometries have been found, even after having carried out several simulations. A new approach has been proposed here, Genetic Algorithm is

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Corresponding Author. Email: kakandikar@yahoo.co.in used for finding out the optimum combinations of the process parameters, geometry parameters and machine parameters for deep drawn components of circular geometry instead of trial and error methods.

2. Problem Formulation

The optimization problem has been formulated with the aim of minimizing drawing load as follows.

Minimize

$$F_{d.\max} = \pi d_m S_0 \left[e^{\mu\pi/2}\ 1.1\sigma_{f,m,I} In \frac{d_{F,\max}}{d_m} + \frac{2\mu F_N}{\pi d_{F,\max} S_0} + \sigma_{f,m,II} \frac{S_0}{2R_D} \right]$$

Subject to;

$$1.25 \le \beta \le 2.2$$

$$3R_D \le R_P \le 6R_D$$

$$F_{d\max} \le \pi d_m s_0 S_u$$

$$R_D \ge 0.035[50 + (d_0 - d_1)]\sqrt{s_0}$$

$$p_{BH} = 10^{-3} c\left[(\beta - 1)^3 + \frac{0.005 d_0}{S_0} \right] S_u \ge 0.250$$

Where $F_{d.\max}$ is the maximum drawing load required, d_m is the mean diameter of cup, S_0 is the sheet thickness, μ is the coefficient of friction, $\sigma_{f,m,I}$ is mean flow stress in the flange and $\sigma_{f,m,II}$ mean flow stress in the cup wall, $d_{F,\max}$ is the maximum diameter of flange of circular cup when drawing load is maximum. R_D Is the radius on die and R_P is the radius on the punch. β is the drawing ratio, S_u is the engineering stress. d_0 is the diameter of blank and d_1 is the diameter of cup. p_{BH} is the blank holder pressure.

3. Variables Affecting the Process

3.1. Forming load

The required drawing load for Forming and its variations along the punch stroke is a rather important parameter in optimization as it determines the distribution of strains in drawn components. An elementary theory equation for drawing load by Siebel has been used for optimization purpose. This equation considers the ideal deformation load, load component produced by friction between die and flange and also between flange and blank holder, the load increase due to friction at the die radius, and the load necessary for bending the sheet around the die radius.

$$F_{d.\max} = \pi d_m S_0 \left[e^{\mu\pi/2} 1.1\sigma_{f,m,I} In \frac{d_{F,\max}}{d_m} + \frac{2\mu F_N}{\pi d_{F,\max} S_0} + \sigma_{f,m,II} \frac{S_0}{2R_D} \right] \quad (1)$$

3.2. Blank holder pressure

The flange contains tangential compressive stresses, which can cause wrinkles due to buckling. Wrinkles can be avoided through the use of a blank holder, which is pressured with a pressure P_{BH} against the flange of the drawn component. It depends on the sheet material, the relative sheet thickness, and the drawing ratio. An investigation by Siebel and Beisswanger shows that the required blank holder pressure can be estimated from following equation, where the factor c ranges from 2 to 3.

$$p_{BH} = 10^{-3} c\left[(\beta - 1)^3 + \frac{0.005 d_0}{S_0} \right] S_u \quad (2)$$

3.3. Cracking load

The largest allowable drawing load is limited by the load that can be transmitted by the sheet in the region of the punch radius or at the transition form cup wall to bottom radius, which is called as cracking load. It must always be larger than the maximum drawing load. The cracking load can be determined approximately by the equation:

$$F_{cr} = \pi d_m S_0 S_u \quad (3)$$

where;

F_{cr} is the cracking load.

3.4. Die clearance

In practice the dimensions of the die clearance are often determined from the empirical equations suggested by Oehler and Kaiser [7]. These equations are valid only for forming of circular components without ironing

$$u_D = s_0 + 0.07\sqrt{10 s_0} \quad \text{(For steel)} \quad (4)$$

If the die clearance u_D is too large, the component does not form a true cylinder; nevertheless the upper edge of the cup remains expanded. If the die clearance is too small, ironing can take place, which increases the drawing load and the danger of cracking.

3.5. Radius on die & radius on punch

The die radius R_D depends on the size of the work piece and its thickness. In order to lower the drawing load and to increase the limiting drawing ratio, large die radii are required. Large radii, however, reduce the contact area between the blank holder and the flange and increase the tendency to form wrinkles in the region of the die radius. Oehler and Kaiser have developed the following empirical equation for the die radius which have been used for optimization [8].

$$R_D = 0.035[50 + (d_0 - d_1)]\sqrt{s_0} \quad (5)$$

The punch radius R_P should be larger than the die radius by a factor of 3-5. R_P must never be smaller than R_D or the punch might pierce the material.

4. Genetic Algorithm – An Evolutionary Approach

Genetic Algorithm is a computerized search and optimization method based on the mechanics of natural genetics and natural selection. Professor John Holland of the University of Michigan, Ann Arbor envisaged the concept of these algorithms in the mid sixties. A Genetic Algorithm simulates Darwinian theory of evolution using highly parallel, mathematical algorithms that transform a set (population) of mathematical objects (typically strings of 1's and 0's) into a new population, using operators such as; reproduction, mutation and crossover [9]. The initial population is selected randomly, which could be the toss of a coin, computer generated or by some other means, and the algorithm will continue until a certain time or a certain condition is met. In order to use GA to solve the problem, variables x_i's are first coded in some string structures. It is important to mention here that the coding of the variables is not absolutely necessary. Binary-coded strings that have 1's and 0's are mostly used. In general, a fitness function $F(x)$ is first derived from the objective function and used in successive genetic operations [9]. Reproduction is usually the first operator applied on a population. Reproduction selects good strings in a population and forms a mating pool. That is why the reproduction operator is sometimes known as the selection operator. In the crossover phase new strings are created by exchanging information among strings of the mating pool. Many crossover operators exist in the GA literature. In most crossover operators, two strings are picked from the mating pool randomly and some portions of the strings are exchanged between the strings. A crossover operator is mainly responsible for the search of new strings, even though a mutation operator is also used for this purpose sparingly. The mutation operator changes from 1 to 0 and vice versa with a small mutation probability, p_m. These three operators are simple and straightforward and after some number of generations they give a solution.

4.1. Algorithm

1. Choose a coding to represent the problem parameters, a selection operator, and a mutation operator. Choose population size , n , crossover probability, p_c ,and mutation probability, p_m. Initialize a random population of strings of size l. Choose a maximum allowable generation number t_{max} . Set $t = 0$.
2. Evaluate each string in the population.
3. If $t > t_{max}$ or other termination criteria is satisfied, Terminate.
4. Perform reproduction on the population.
5. Perform crossover on random number of pairs.
6. Perform mutation.
7. Evaluate string in the new population. Set $t = t + 1$, and go to step 3.

4.2. Algorithm parameters

The strength of the Genetic Algorithm is its parallel processing. It works with population and process that much of candidate solutions simultaneously. The greater the population size, the greater the candidate solutions. There is higher probability to get optimal solution. A population size of 1000 is selected here for achieving best accuracy. The algorithm will work for 1000 generations to achieve optimal solutions. Two point crossover exchanges best information from parents to give birth to fittest children. Tournament selection selects more fit candidates with respect to objective function. Mutation probability is kept less as/than 0.005 to find out local solutions and selection probability is kept as 0.85 to get optimal solutions.

Table 1. Genetic Algorithm parameters for optimization

Population	1000
Generations	1000
Reproduction Type	Two Point Crossover
Selection Type	Tournament Selection
Elitism	1
Mutation Probability	0.005
Reproduction Probability	0.9
Selection Probability	0.85

5. Automotive Component under Study

An automotive component-spring seat manufactured by Vishwadeep Enterprises, Bhosari, Pune, Maharashtra is selected for the study. It is/has three stages drawn component. The company still manufactures it with trial and error methods and all the process parameters as well as dimensions of the product are decided within the given tolerances of customers.

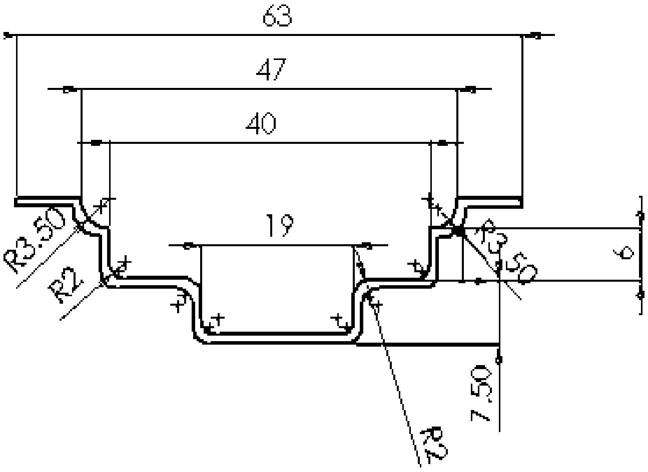


Figure1. Spring seat – original geometry.

The Flange diameter is 63 mm, the first draw diameter is 47 mm, second draw diameter is 40 mm and last draw diameter is 19 mm. The corner radii are 3.5 mm and 2 mm. The step heights are 3.5 mm, 6 mm and 7.5 mm. It is found that, when this component is manufactured with above specifications, many times cracking takes place during drawing itself and also during the use of component. The component material is mild steel which has thickness of 1 mm and ultimate tensile strength of 282.14 *Mpa*.

6. Proposed Methodology

For optimizing the geometry of the spring seat the optimization problem has been formed with the aim of optimizing the maximum drawing load required. The objective function for the drawing load is selected, which is expressed in terms of all the related geometry parameters, process parameters as well as machine parameters. The constraint equations have been formulated in terms of geometry parameters as blank diameter, drawing ratio, diameters of cup and corner radii of cup, machine parameters such as radius on die and radius on punch and process parameters such as blank holder pressure and coefficient of friction. All these variables are optimized with Genetic Algorithm with due respect to material properties and working conditions. The formability analysis is carried out of both the original geometry supplied by the industry and optimized geometry with a finite element analysis simulation software FAST FORM ADVANCED. The failure limit diagrams are plotted to study and compare the formability analysis results of both the geometries and results are concluded.

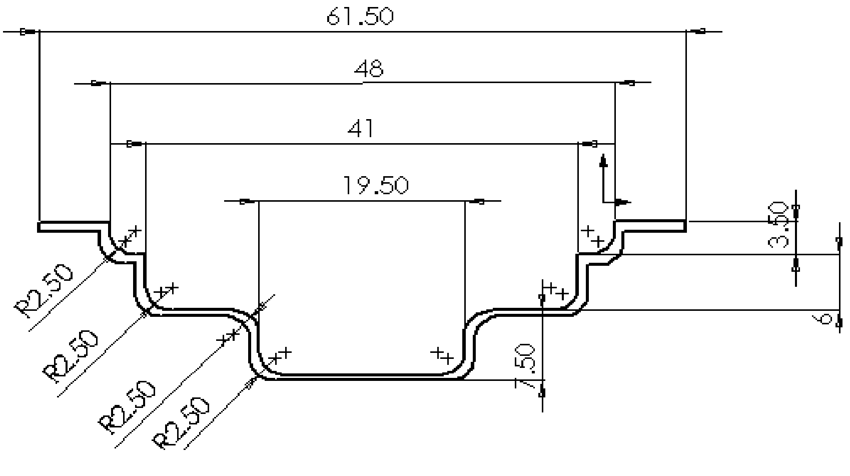


Figure 2. Spring seat – optimized geometry.

6.1. Optimized design for automotive cup

After the optimization of Forming for spring seat with Genetic Algorithm the geometry has been changed as in Figure 2. In the new design various diameters of the spring seat are changed. Cup diameter is changed from 47 to 48 at first stage and 40 to 41 at second stage and from 19 to 19.5 at third stage. Diameter of flange is changed from 63 to 61.5. Corner diameter between wall and base is changed from 3.5 to 2.5 at first stage and from 2 to 2.5 at second and third stage, where as all the heights of the cup remains unchanged as 3.5, 6 and 7.5 for three stages.

7. Results and Discussions

7.1. Forming zone

The optimized design has less amount of loose material when compared to original design. Also it has less amount of tight panel than the original. The red color indicates tight panel and green color indicates loose material. Violet color represents wrinkling tendency, whereas gray color indicates low strain region.

7.2. Safety zone

The original geometry shows some regions with failures (red) whereas the optimized geometry has no failure region. Both have same areas with wrinkling tendency in the flange.

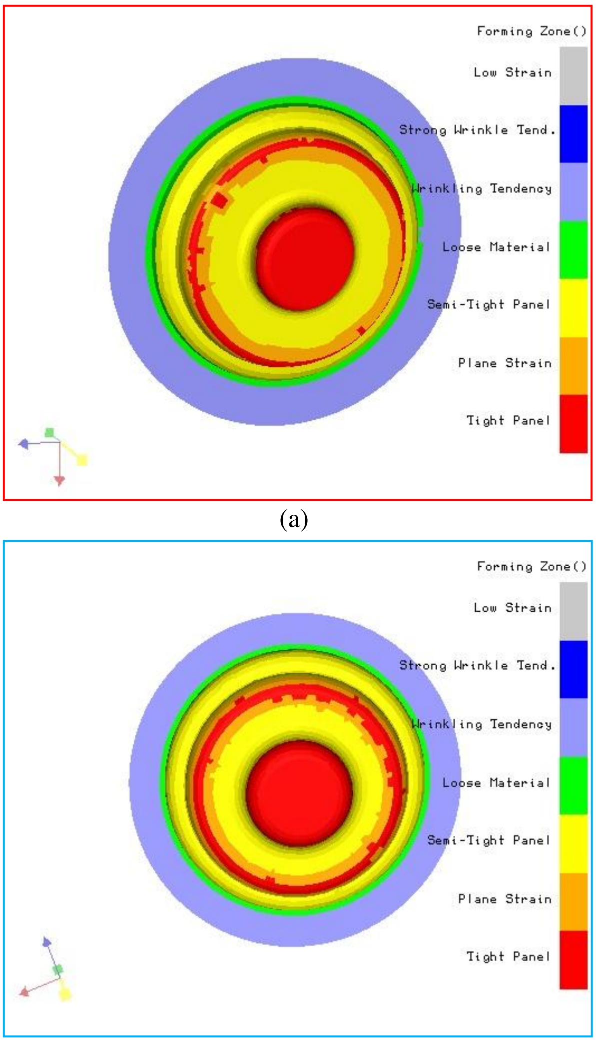
Failure zone i.e. red has been converted to marginal zone i.e. yellow in optimized geometry. Green color indicates safe region.

7.3. Major strain distribution

The maximum major strain with the original geometry is 97.89% and with optimized geometry it is 51.29%. It proves that there is optimum stretching in the direction of major axis. The blue color represents low engineering major strain and red color indicates maximum engineering major strain. In between colors it represents the range from lower to higher.

7.4. Minor strain distribution

The maximum and minimum minor strain with original geometry is 18.53% and -21.55%. Whereas with the optimized geometry maximum minor strain is 17.52% and minimum minor strain is -15.48%.



(a)

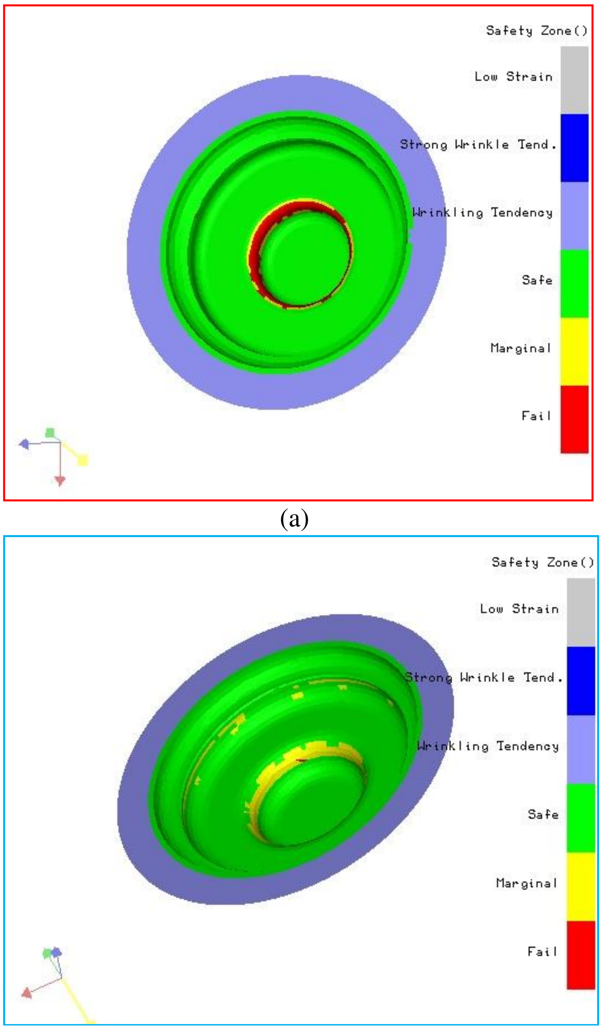
(b)

Figure 3. Forming zone for spring seat – (a) original and (b) optimized geometry.

This proves optimum stretching in the direction of minor axis with improved design. The blue color represents minimum value of engineering minor strain and red color represents maximum engineering minor strain.

7.5. Thickness distribution

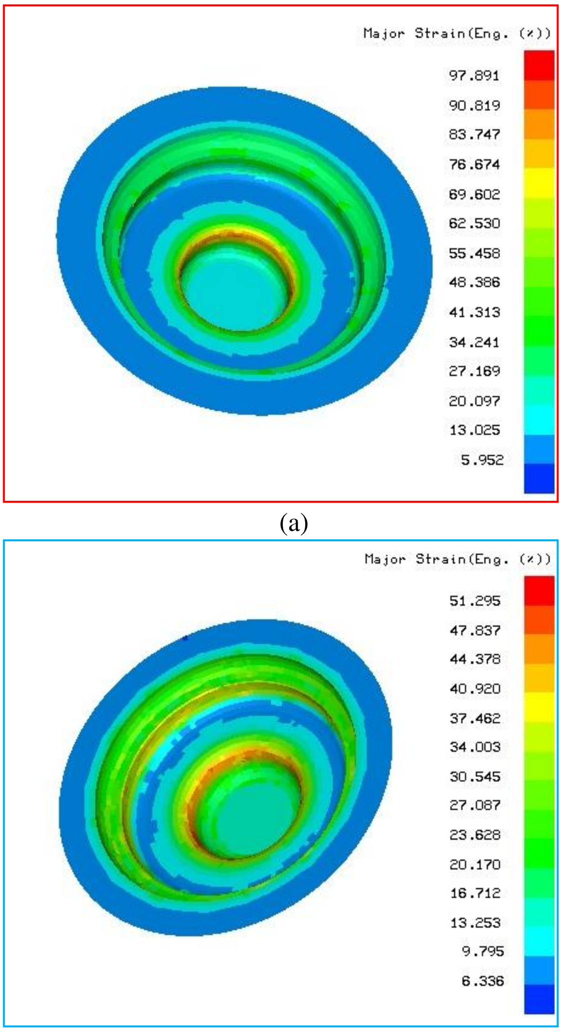
The minimum thickness in crucial area for the original spring seat is 0.587 and that of optimized spring seat is 0.623. This indicates that there is more thinning in original geometry that optimized, which can result into cracking. Lowest thickness is represented by red color and maximum by blue color. Green zone represents safe area.



(a)

(b)

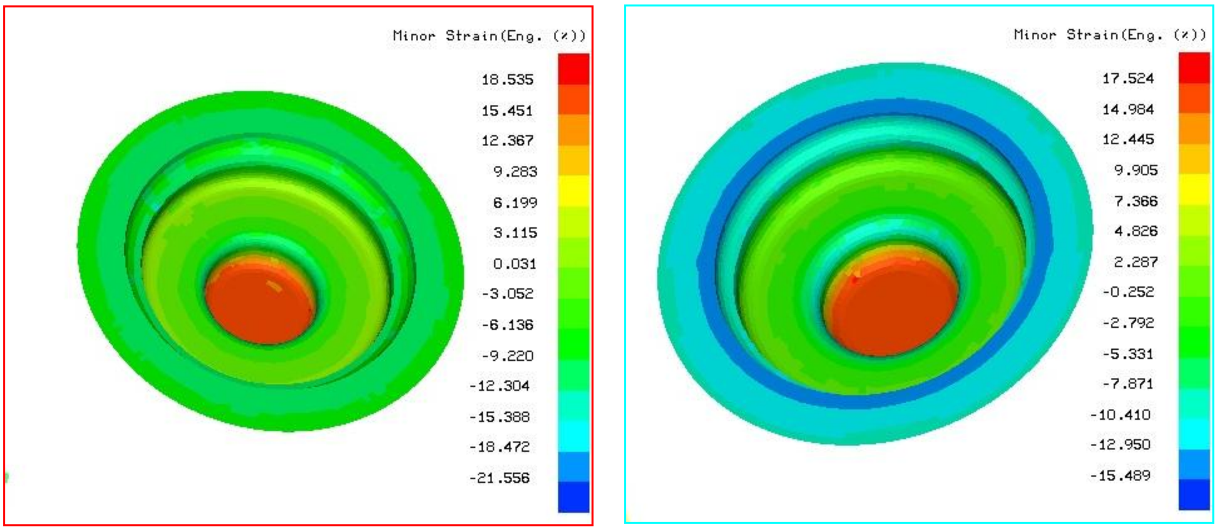
Figure 4. Safety zone for spring seat – (a) original and (b) optimized geometry.



(a)

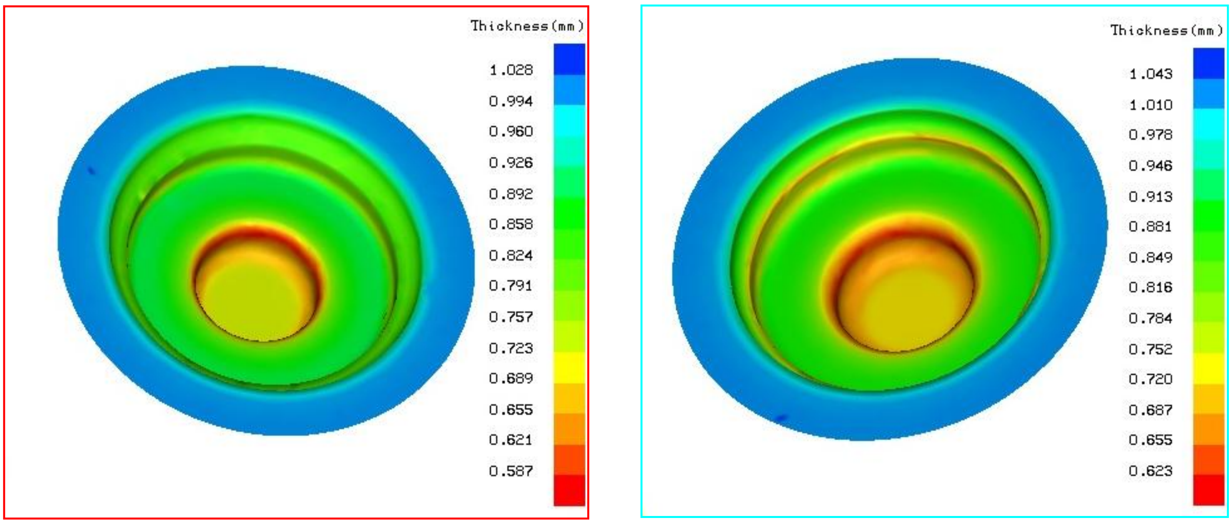
(b)

Figure 5. Major strain distribution spring seat – (a) original and (b) optimized geometry.



(a) (b)

Figure 6. Minor strain distribution spring seat – (a) original and (b) optimized geometry.

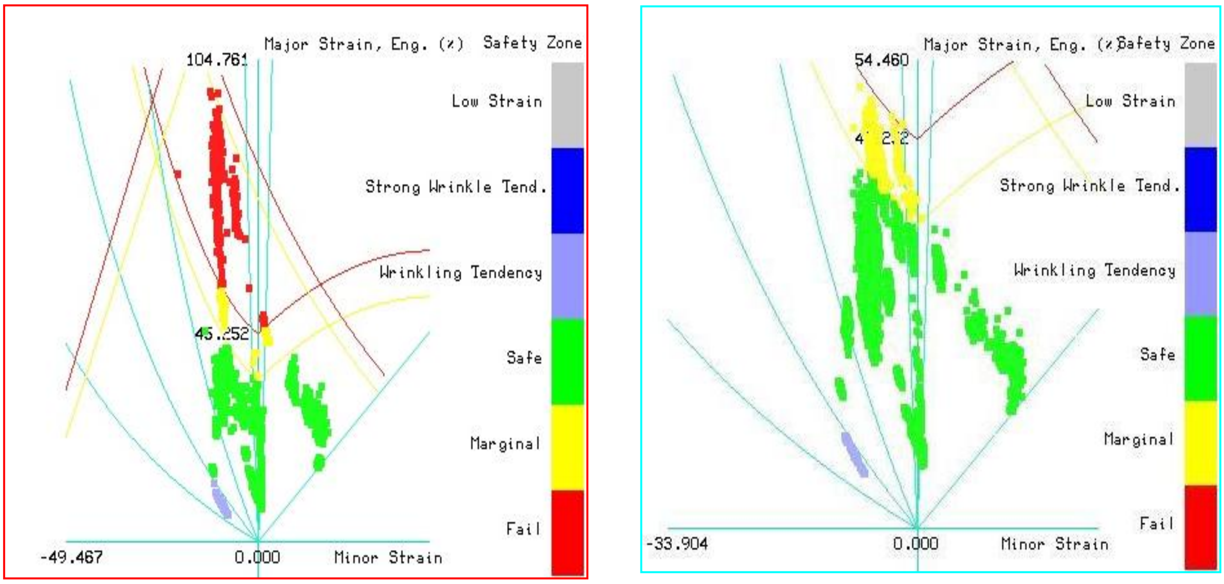


(a) (b)

Figure 7. Minor strain distribution spring seat – original and optimized geometry.

7.6. Failure limit diagrams

The optimized geometry of the cup requires a maximum drawing load of 62390.35 N whereas the original geometry requires a drawing load of 74788.53 N. There is 16.57% reduction in the forming load. The appropriate capacity press can be selected by knowing the drawing load. Working with the presses of higher capacities may lead to many types of defects such as cracks and tearing. Blank holder pressure has been optimized from 1.750 N/mm^2 to 1.766N/mm^2 for optimized geometry. The coefficient of friction is optimized from 0.13 to 0.10 for new geometry. The red color points represent failure points. Yellow color represents marginal points. Green represents safe zone. Violet color indicates wrinkling tendency.



(a) (b)

Figure 8. Failure limit curves spring seat – original and optimized geometry.

8. Conclusions

The failure limit diagram for original geometry shows some failure points [Red] along with safe points [Green] whereas the optimized geometry does not show any failure points. The major strain for the original geometry is 104.76 *Mpa* whereas it is optimized to 54.46 *Mpa* for optimized geometry. The minor strain for new geometry is optimized as -33.90 from that of original -49.46. Maximum drawing load and blank holder pressure are optimized which enable selection of proper capacity press. The other process parameters and geometry parameters are also optimized. With all these new parameters the failure limit diagrams for new geometry do not show any failure points. Therefore it is safer and hence more optimal than the original design.

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Dr. ***Vilas M. Nandedkar*** *has completed his Ph.D. in Metallurgy from Indian Institute of Technology Bombay, Mumbai. Presently he is working as Professor in Production Engineering in Shri Guru Gobind Singhji Institute of Engineering & Technology, Nanded, M.S. India. This is Autonomous institute of Government of Maharashta. He has published more than hundred papers at international & national level. 6 candidates have completed Ph.D. under him and he has guided several M.Tech.Projects. His research areas are Metal Forming, Metallurgy, Technology Management & Optimization.*

Prof. ***Ganesh M.Kakandikar*** *has completed his masters in Mechanical Engineering & pursuing Ph.D. from Shri Guru Gobind Singhji Institute of Engineering & Technology, Nanded, M.S. India. He is presently working as Assistant Professor in PG Department with specialization in Computer Aided Design, Manufacture & Engineering at Dnyanganga College of Engineering & Research, Pune, India. He has more than 25 papers to his credit at National & International level. His areas of interest are Metal Forming, Evolutionary Optimization & CAD/CAM/CAE.*